Eye activity correlates of workload during a visuospatial memory task

Karl. F. Van Orden[1], Scott. Makeig[2], Tzyy-Ping Jung[3], Wendy Limbert[2]

SPAWAR Systems Center San Diego

1. Space and Naval Warfare Systems Center, San Diego, CA, 92152-5001 USA
2. Naval Health Research Center, San Diego CA, 92186-5122 USA
3. University of California – San Diego, CA, USA

Introduction

Assessing and predicting human workload is an important consideration in the design process of new systems, the modification of existing systems, or for the purposes of alleviating or avoiding task overload in real time through task reallocation or adaptive automation. Previous research has established that truly adaptive systems require information on the human operator's workload levels in real time, as it is difficult to reliably predict actual workload based upon a prioi modeled estimates alone (Byrne & Parasuraman, 1996; Parasuraman, Bahri, Deaton, Morrison, & Barnes, 1992). The combination of several eye activity measures may provide a psychophysiological estimate of workload for some tasks. Pupil diameter has been shown to increase with higher cognitive workload (Granholm, Asarnow, Sarkin & Dykes, 1996), while blink rate and duration decline as a function of greater visual demands imposed by a task (Wilson, Fullenkamp & Davis, 1994). Likewise, fixation parameters (dwell time and frequency) also show workload-related changes (Hawkins & Wilson, 1998). Here, we demonstrate signal processing methods that make possible the identification of eye measures most sensitive to task demands. We then assess the sensitivity of nonlinear and artificial neural network (NN) models using combined eye measures to predict moment-to-moment fluctuations in task workload.

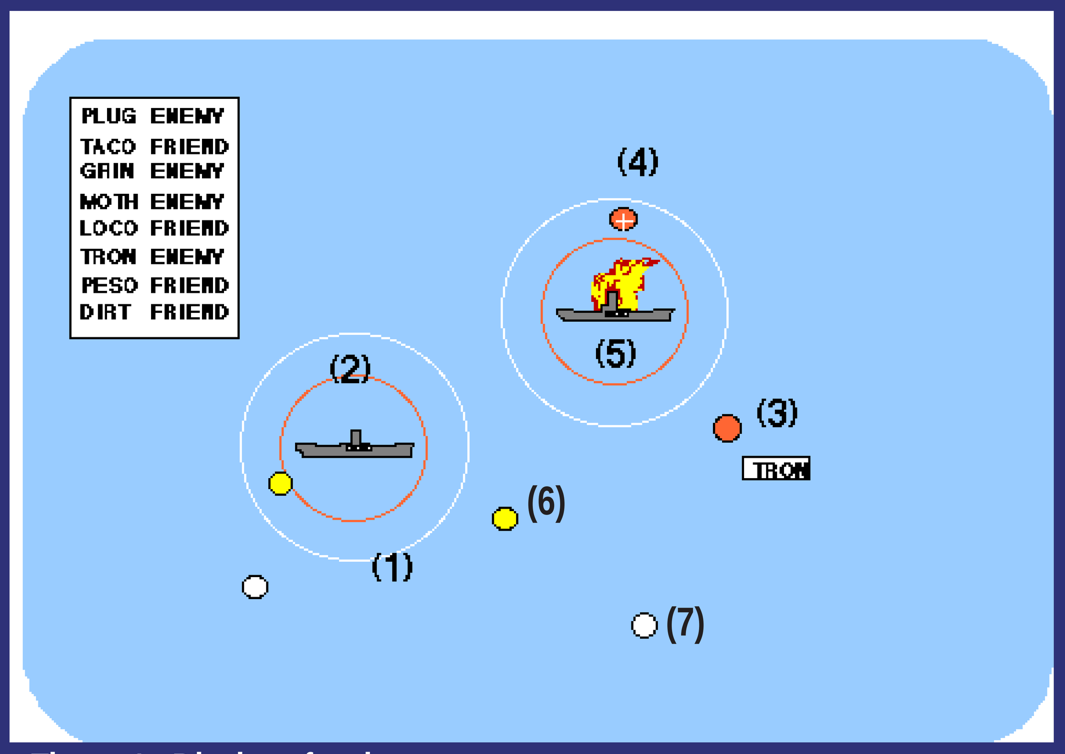


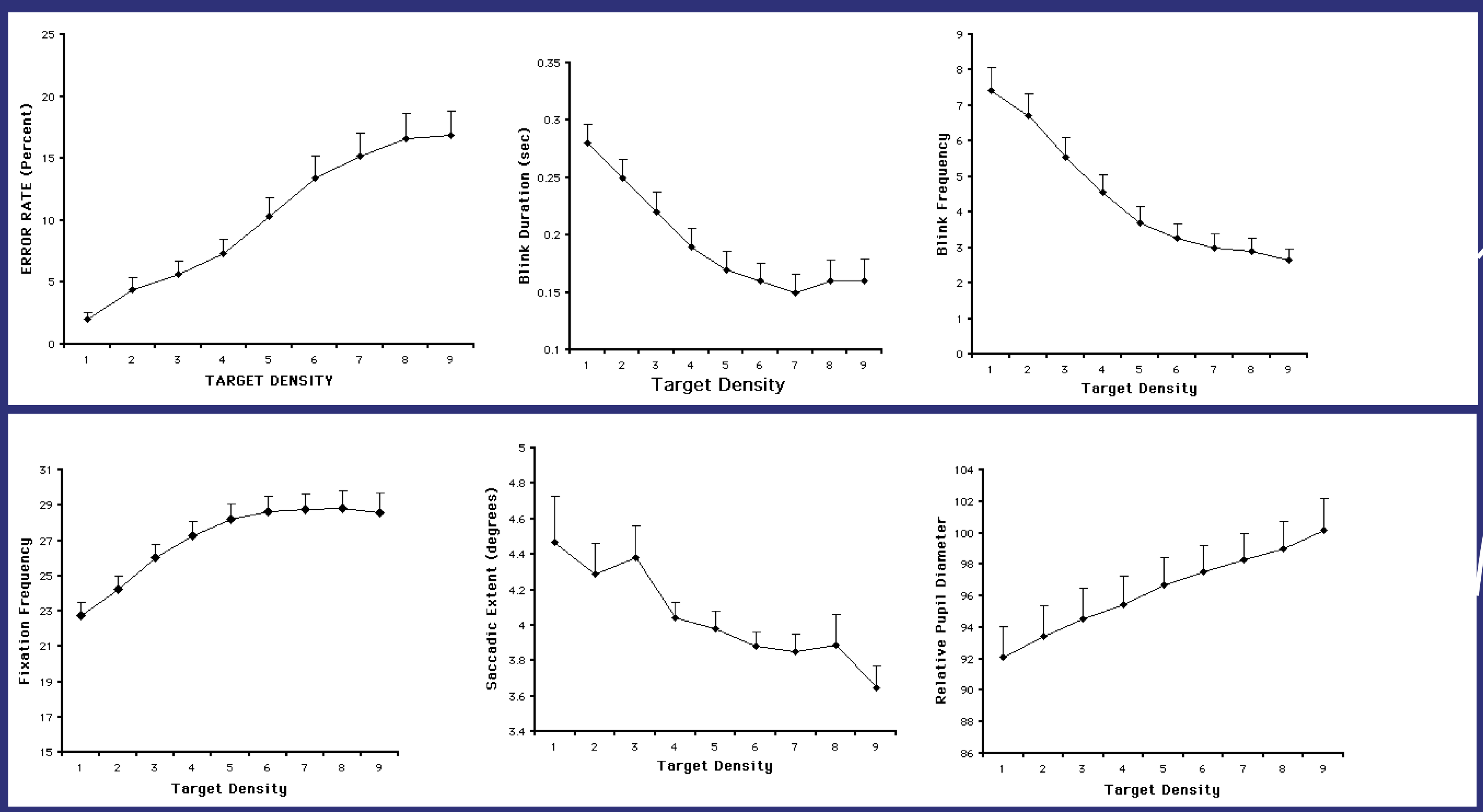
Figure 1. Display of task.
1) Outer range ring 2) Inner range ring 3) Target being classified
4) Enemy target correctly fired upon 5) Enemy target not fired upon – ship is hit 6) Classified target 7) Unclassified target

Method

Participants: Eleven paid volunteers (5 females, 6 males, 20 to 54 years old, mean age = 31.6 years,) completed the study.

Task Description: A mock air warfare task (similar to the target/threat identification task originally developed by) and was run on a 80486 computer. Based on a task developed by Ackerman and Kanfer, 1994, the goal was to allow "friendly" targets to pass over and to fire upon "enemy" targets that approached two ships on the display. The subject was required to classify each white circular target symbol as a friend or an enemy, and to destroy enemy targets while they were between two range rings around the ships. Friendly targets were allowed to pass. The subject had to select a target and remember its classification (from a list displayed at the upper left corner of the display. The list dissapeared after the target was classified.

Procedure: Eleven subjects completed four 2h blocks of the task. Between one and nine targets could be simultaneously present on the display. Eye activity measures were recorded at 60Hz from an ASL 4000SU near infrared eye tracking system. For each participant, moving estimates of blink frequency and duration, fixation dwell time and frequency, and pupil diameter, integrated over periods of 20s or less, were obtained every 2s.



Moving mean estimates of eye activity obtained from blink, fixation, and pupil data streams every 2 sec. Blink windows: 20 sec, Fixation windows: 10 sec, Pupil diameter window: 3 sec

Regression Results (sessions combined)

General Model: Workload = -0.45 * BF + 0.22 * FF + 0.12 * PD

Where BF = deviation from baseline blink frequency
FF = deviation from baseline fixation frequency
PD = deviation from baseline pupil diameter

The correlation coefficient (R) of general model-derived estimates of target density with actual levels was 0.55.

Table 1: Individual Participant Standardized Regression Models of Visual Workload

P#	BF	FD	FF	PD	LF	ADDITIONAL TERMS		R
1	0.45		-0.19			0.23 (BF2)-0.15 (BD*FF)		0.75
3	0.32		-0.15					0.39
4				-0.31		0.20 (PD2)		0.39
5	0.35				-0.19	-0.20(BF*PD)		0.56
6						-0.20 (BF*LF)		0.73
7			-0.37			0.30 (FF*LF)		0.44
8	0.44			-0.38				0.68
9	0.51		-0.25			0.24 (BF2)		0.76
10	0.57					-0.23 (BF*FF)	0.15 (FD*PD)	0.71
11	0.41		-0.33			-0.26 (BF*PD)		0.79
MN								0.62

Notes:
1. BD, Blink Duration; BF, Blink Frequency; FD, Fixation Duration; FF, Fixation Duration; PD, Pupil Diameter; LF, Long Fixations
2. Correlation coeficients exceeding 0.36 are significant to the $p < .01$ level
3. Data for Participant 2 was excluded from the data analysis due to excessive error rates at high target densities. The final sessions of Participants 3 and 5 were excluded for the same reasons.

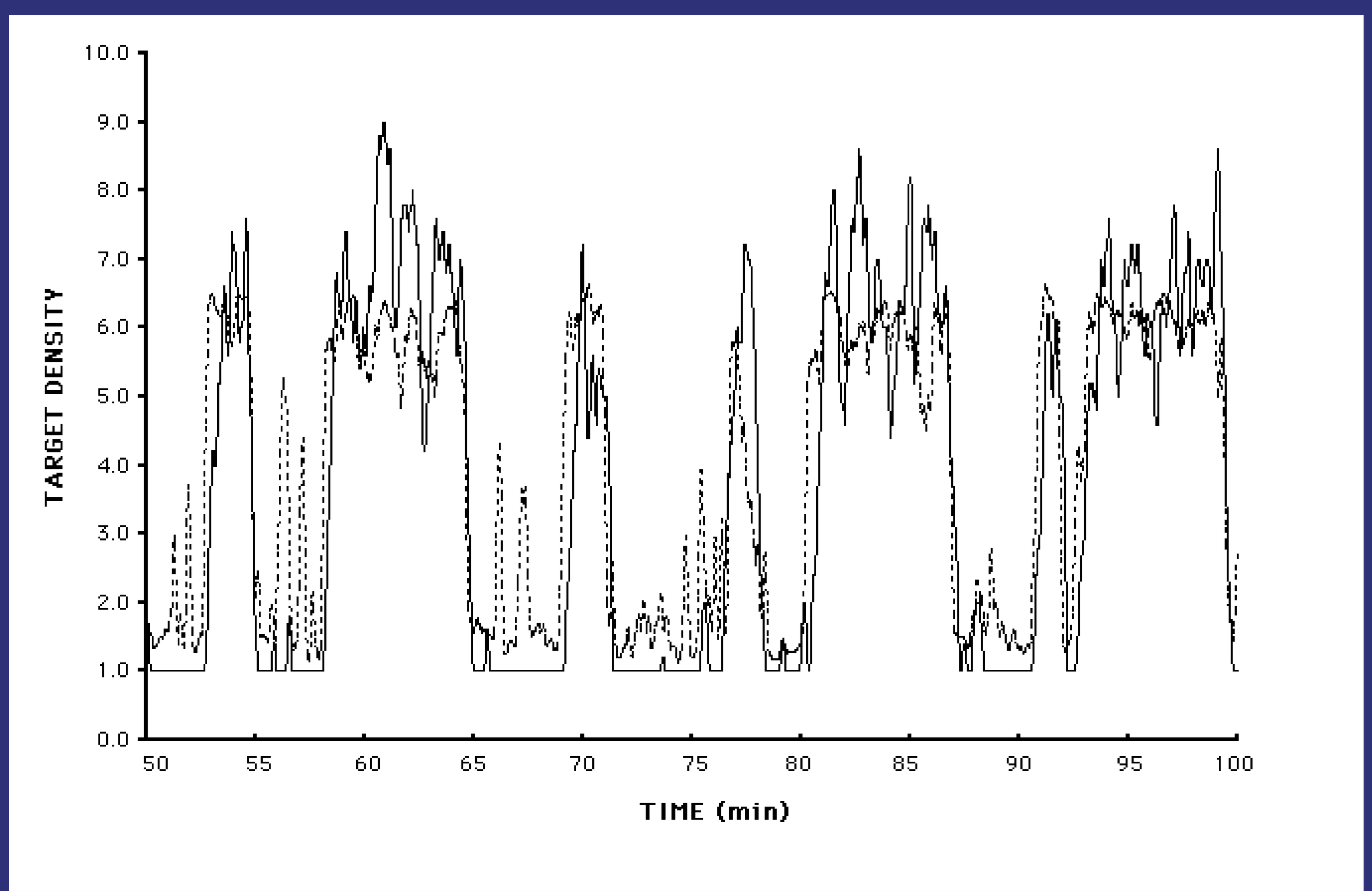
Table 2: Within and Between-Session Neural Network Correlation Coefficients (R)

Participant	Session	Within-session	Between-session
1	A	0.78	0.65
	B	0.77	0.69
	C	0.88	0.85
3	A	0.48	0.33
	B	0.57	0.47
4	A	0.81	0.70
	B	0.64	0.52
	C	0.27	0.06
5	A	0.74	0.67
	B	0.65	0.57
	C	0.59	0.50
6	A	0.79	0.72
	B	0.78	0.72
	C	0.79	0.76
	D	0.83	0.77
7	A	0.68	0.51
	B	0.71	0.50
	C	0.63	0.56
8	A	0.75	0.66
	B	0.76	0.56
	C	0.76	0.74
	D	0.82	0.64
9	A	0.78	0.71
	B	0.84	0.79
	C	0.87	0.85
	D	0.81	0.79
10	A	0.79	0.78
	B	0.76	0.72
	C	0.76	0.68
	D	0.73	0.72
11	A	0.88	0.75
	B	0.88	0.83
	C	0.85	0.82
	D	0.87	0.83
Mean		0.74	0.66

Note: Cross-session correlation coeficient (R) is 0.68 if session C from Participant 4 is excluded. Correlation coeficients exceeding 0.36 are significant to the $p < .01$ level

Neural Network Results

Three-layer perceptron, back propagation trained. For each subject, two-thirds of data used to train NN, validated on remaining one-third of trainng data set. Five networks trained, median performing net used for cross-session validation.



Plot of the neural network-derived workload estimate (dashed line) superimposed on actual target density (solid line) during 50-min of Participant 9's second session (R = 0.79, RMS estimation error 1.36 items). The neural network was trained on data from this participant's three other experimental sessions.

CONCLUSIONS

- Information from multiple eye measures may be combined to produce reliable and near real-time estimates of cognitive and visual workload for some visuospatial tasks.

- The results extend work conducted previously on eye activity correlates of performance during a sustained tracking task (Van Orden, Jung & Makeig, 1999).

- The use of moving-mean estimates of pupil, blink and fixation measures with relatively brief integration times and individualized NN models represents a significant progression of eye-activity based psychophysiological assessment of workload.